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THE CELESTIAL GUARDIANS "CASTOR AND POLLUX" WILL SURVEY AIRPLANES CROSSING THE ATLANTIC

by Jean-Claude Trichet

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ABSTRACT. The article describes the uses and functioning of the twin satellites "Castor and Pollux" according to a project prepared by French specialists. Special stress is laid on the expected future overcrowding of air space above the North Atlantic. The author deals with the risk of collisions, and the utilization of the satellite system for avoiding them.

Another challenge which is not American: to the best of our knowledge, a single complete project exists to date for the survey of air traffic with satellites; it has been submitted by France within the scope of the work accomplished by the four-power commission (USA, Canada, United Kingdom, France); the task of the commission was: to study problems of aerial navigation over the North Atlantic. We have presented the outline of the project named "Dioscures" (children of Jupiter) in the number 222 page 34 of "Air and Cosmos". The name Dioscures was used in Greek mythology for the twins Castor and Pollux. Like the Roman warriors, the French specialists of C.N.E.S. and of S.G.A.C. now intend to apply to these blessed twins of the gods, to win a battle which appears to be difficult. The point at issue today is: how to eliminate the overcrowding of aerial space above the North Atlantic. We will point out right here that the French recommendation is applicable to the survey of whatever zone on our planet. The modern "celestial twins" will be two satellites (see this issue, page 16) which will serve to survey increasing numbers of commercial airplanes.

The international specialists to whom the C.N.E.S. and the S.G.A.C. presented their project welcomed it; this encouraged the aforementioned organizations to proceed with the definition o the project. The invitation of tenders for the development of the most delicate features of the system have already been issued. Airplane antenna study contracts will be concluded during the first months of 1968.

In other respects, the definition of the system utilizes various techniques which have already been developed within the scope of other programs, especially for the adjustment of a miniaturized transponder entirely "solid state", with frequency band L (1,500-1,600 MHz).

What a Crowd Above the Water

But why is it necessary to resort to satellites (at least two) to survey the traffic of airplanes over the North Atlantic? The question involves economics, and the safety of air traffic. All specialists agree that the present system will be condemned before long. According to the present system, the crew of an airplane underway is requested to signal the position of the airplane at regular intervals to the control centers which also make sure that no risk of a collision between two airplanes exists. During this time, the airplanes are beyond the range of standard control systems (radar). Separations have been defined by taking into consideration the frequency of information exchanges possible between airplanes and control centers and on the other hand, by taking into consideration the effective precision of navigation position-finding. Minimal distances must be observed between airplanes from the moment when they are beyond communications by positive means (radar). The distances must be sufficient to reduce the risk of collisions to a minimum (admittedly, the possibility of one collision per 10 million flight-hours exists).

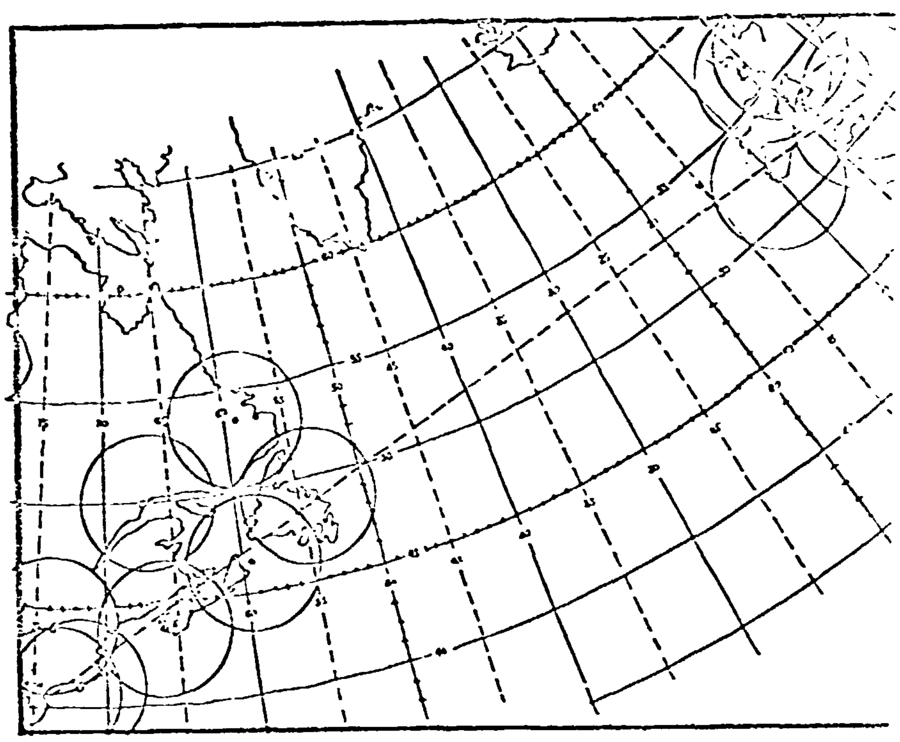

Figure 1. This is the zone actually covered by the range of V.H.F. from the regional control centers.

At present, airplanes flying over the North Atlantic are laterally separated by 120 nautical miles; the longitudinal separation is 15 mm of flight, and vertically 2,000 feet. It is understandable, under these conditions, that as the number of airplanes flying over this zone increases, most of the airplanes will have to use routes which will diverge more and more from the optimal routes. Since possibilities for detouring are limited, the aerial traffic volume possible under such conditions is also limited. Since 1963, the number of trans-Atlantic flights has increased by about 15% each year. In 1964, during periods of peak traffic, up to 25 airplanes per hour have been counted, flying in the same direction above Gander (Newfoundland). Most fortunately, peak traffic is not simultaneous both ways. Even under these conditions, it can be estimated that up to seven airplanes were simultaneously above the North Atlantic, considering that a jet-propelled plane spends about four hours in this zone. Among the studies on the probable evolution of air traffic, the study made by the Boeing Company seems to be the most realistic. It shows that the traffic volume will become stable with about 200 airplanes after 1975 (maximal number of airplanes flying simultaneously over the North Atlantic zone). If one estimates that 40% of the traffic in 1980 will be implemented by supersonic airplanes it seems reasonable to foresee simultaneously 120 subsonic airplanes and 80 supersonic airplanes simultaneously flying over the North Atlantic by that time.

Temporary Solutions

The methods used at present for controlling air traffic in ocean zones cannot guarantee the required traffic safety. It is generally admitted that a new system should be available by 1973-1975 (report of specialists of the Organization of International Civilian Aviation).

By then, numerous specialists plan to improve the present system, from 1970, so as to make an intermediary system available. The most frequently considered improvement involves the automatic transmission of airplane positions, by numerical signals transmitted directly by the calculator on board to the radio transmitter. On the strength of such position reports, the operators of the control centers could forecast the collision risks and could suggest corrective orders to the control staff, to be transmitted to the airplanes concerned. Such measures are planned for inert navigation systems developed at present. Let us refer also to the "Data-Link" of the Decca Navigator Company Ltd., which works with a navigation calculator named "Omnitrack" (see "Air and Cosmos" No. 205). But such an installation is of interest only on two conditions: the navigation system must be more precise than the present systems, and long-range radio communications must be available. As for the second point at issue: it seems indicated

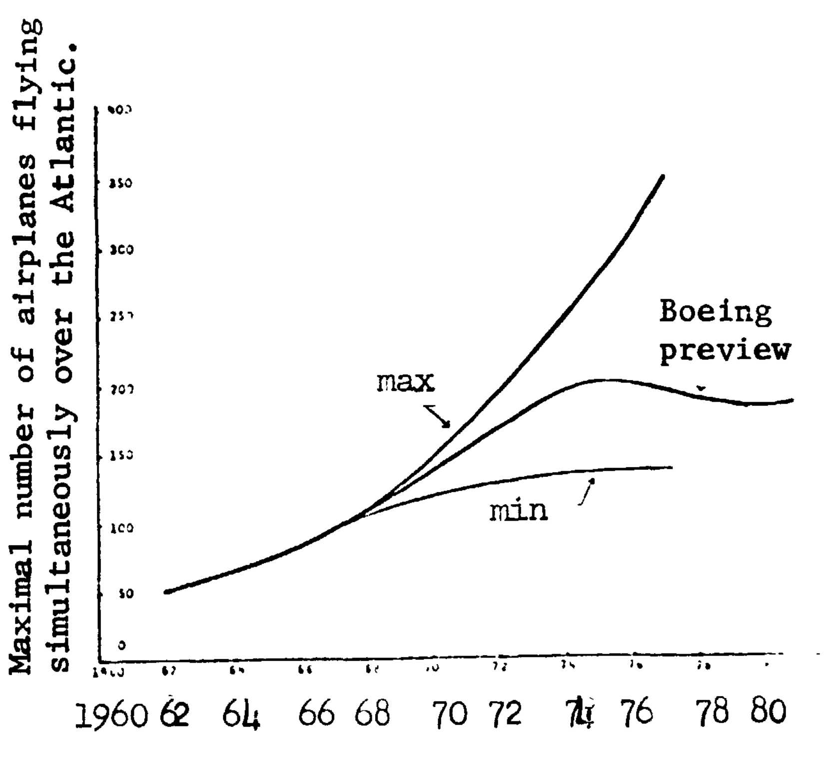

Figure 2. Preview of traffic evolution of the North Atlantic. The maximal curve has been plotted by extrapolating the present increase. The minimal curve has been plotted in 1966 by the Rand Corporation. The Boeing curve takes increased passenger traffic volume, freight shipments and the equipment estimates of the companies into consideration. The estimate involves a Boeing 747 equivalent to 3B. 707, a Concord equivalent to 1.5 to 2B. 707 and an SST equivalent to a 4B. 707.

to resort to relay by satellite, because the only available communications available at present, at H. F. (4 to 27.5 MHz) are unreliable and capricious. We have disclosed the American preposition for solving this problem by using VHF satellite relay (see "Air and Cosmos" No. 221). This frequency band (118-136 MHz) is a more reliable communications system, but it requires satellite relay because VHF radio waves do not propagate beyond the horizon (rare cases excepted, the causes of which are still insufficiently known). Unfortunately, this frequency band is overcrowded to such an extent that the reduction of the channel spacing from 50 to 25 kHz is being considered. The widening of this band by encroaching on special frequencies jointly used by airplanes and ships has also been considered, especially for international prohibition of navigation in danger zones (cases of parachute landing parameters). But the International Telecommunications Union was of opinion that this could not be done on a permanent basis. On the other hand, the widening of the airplane antenna band, especially in the lower range, involves difficult technological problems which could not yet be completely settled, even for subsonic airplanes. It was also understood that the average VHF board transmitter for satellite communications is rather heavy (500 W with materials used at present for experimental purposes).

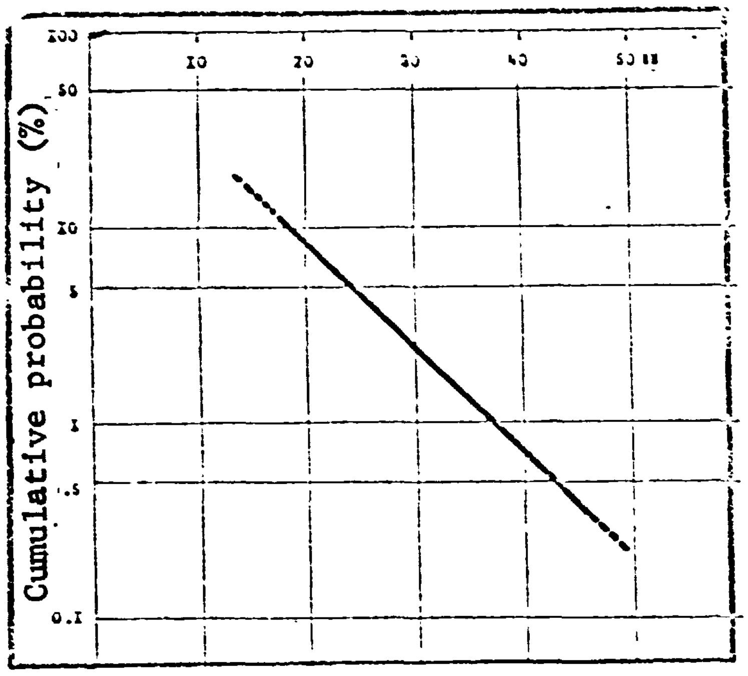

Figure 3. Statistical study of the Royal Radar Establishment concerning navigation errors during the crossing of the North Atlantic. The abscissa shows errors beyond the given ceiling (in nautical miles).

A future solution should be found for economic reasons. But if VHF communications via satellite are feasible, serious difficulties arise when developing an auxiliary system for VHF navigation by satellite. It is generally known that systems functioning on this band (V.O.R. I.L.S. D.M.E.) are unrealiable; in addition, VHF transmission in the ionosphere involves risks (see "Air and Cosmos" No. 222, p. 34). These risks could be eliminated by resorting to radar techniques with compression impulsion, requiring the use of a 200 W transmitter with cresting power on board the satellite.

Another unfavorable feature of VHF: the low capacity of airplane antennas would lead to high costs when localizing retransmission satellite bands; this maneuver would involve the use of a considerable part of the power available on the satellite. The studies of C.N.E.S. and of S.G.A.C. have shown that a system has to be found immediately for considerably reducing the separation ratio between airplanes.

The Control Will Control

It seems that the only possibility for reducing separations at present is to resort to the "positive" control also called "tactic" control of airplanes, similar to a system used over land zones with large traffic volume. In these zones, the airplanes are controlled by a radar network ("primary" and "secondary" radars) and the traffic controllers contact the pilot by radio if he deviates from the air corridor in which he is supposed to fly. We have stated earlier that the present situation could be improved with a more precise navigation system. Two systems with each other although they are in fact complimentary: the inert system (see "Air and Cosmos" No. 206) and the hyperbolic aids such as the Dectra (see "Air and Cosmos" No. 205). It results that when correcting navigation errors with these systems, the separations cannot be diminished considerably without increasing, (statistically) risk of collisions. One must also consider that all long-distance airplanes will not be provided with the same material, and that the effects of wear on these materials is little known. It is, however, planned to use the position reporting system for verifying, and the satellite position-finding system will be used for correcting, the navigation of the airplanes.

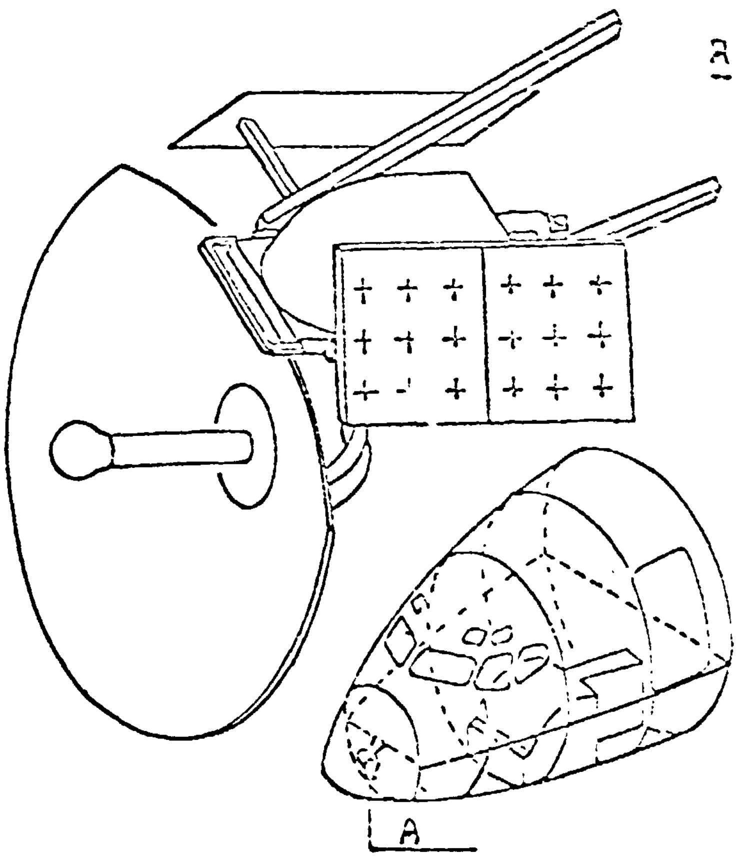

Figure 4. Proposed installation of two airplane antennas with electric scanning, for the radio installation of a Boeing 707, above the antenna of the meterological radar.

Should it become necessary to use an intermediary system before utilizing satellites as navigational aids, French specialists are of opinion that it would be best to accept the British proposition. The British experts of the four power commission have recommended the establishment of stable maritime stations in the North Atlantic, provided with VOR-DME standard ground beacons and radio relay systems. Anchored ships would serve as such stations, with platforms similar to those of the oil-drilling installations on the sea. However, the cost of such installations and especially the operation of the stations, would certainly be much higher than the cost of a satellite system.

Satellites and Lasers

The Dioscure project is based principally on the timing of radio signal propagation between airplanes and ground stations in corresponding satellite channels. This information would be completed by automatic transmissions from the airplane, reporting its altitude.

The control station transmits to the nearest satellite a signal indicating which airplane's position is required. These two emission would be in the frequency band 6,000 MHz; the signal would pass over the given transmission channel. The satellite amplifies the received signals and transmits them through band 1,600 MHz to their destination on the airplanes. An airplane, recognizing his signal will retransmit the signal on a different frequency and will report its altitude over the given transmission channel. The two satellites will then relay the signal to the control station.

All airplanes are contacted in this manner according to an automatic cycle which is renewed every five minutes. The signals received by the control center are then handled by selector. Two replies are received for each interrogation, corresponding to the replies relayed from the airplane by the two satellites. The calculator plots the distance between the airplane and the satellite from the time which passed between the transmission and the reception of the reply. On the strength of the consecutively received points, the calculator estimates the future position of the airplane. If it is found that it deviates too much from its flyway, the controller is informed and emits a correction order to the pilot. Using frequency Band L, standard deviations are rated at 750 meters. Taking the dispersion rate into consideration, this permits evaluation of the position of the airplane within about two nautical miles. Such precision in locating an airplane is achieved by taking imprecisions of 300 meters into account where plotting the altitude of the airplane.

It is understandable that the precision of airplane position finding depends on the precision with which the position of the satellite can be plotted. On the basis of experience gained with the satellites "Diademe", the C.N.E.S. plans to use a system of laser telemetry which permits finding the position of satellites within about 10 meters.

Presupposing that the control centers can intervene once every five minutes at the most, this system can be used for assuring the safety of 200 airplanes flying simultaneously over the North Atlantic; their lateral separation would be reduced to less than 60 nautical miles and to 10 mm in longitudinal flight.

Hello, Satellite, Let Me Take Control

Besides distance-plotting transponders, the satellites would carry equipment for radio communications between airplanes and the ground (and vice versa). It has been planned to provide two retransmission telephone channels and one channel for the transmission of data for each satellite.

The equipment on board the airplane would include two antennas and a transponder. The latter would be in a standard container demi-ATR with two transmitters (position-finding signals and telephone line) and each would have 20 W power. The antennas are of the electric scanning type, and each has two beams with similar features. The diagrams of the beams have an opening of approximately 20^{o}; the reception is with 12 and 15 dB depending on the deflection angle of the beam. The entire airplane installation should not weigh more than 30 kg., reinforcement structures not included; the latter might be needed for the built-in antenna.

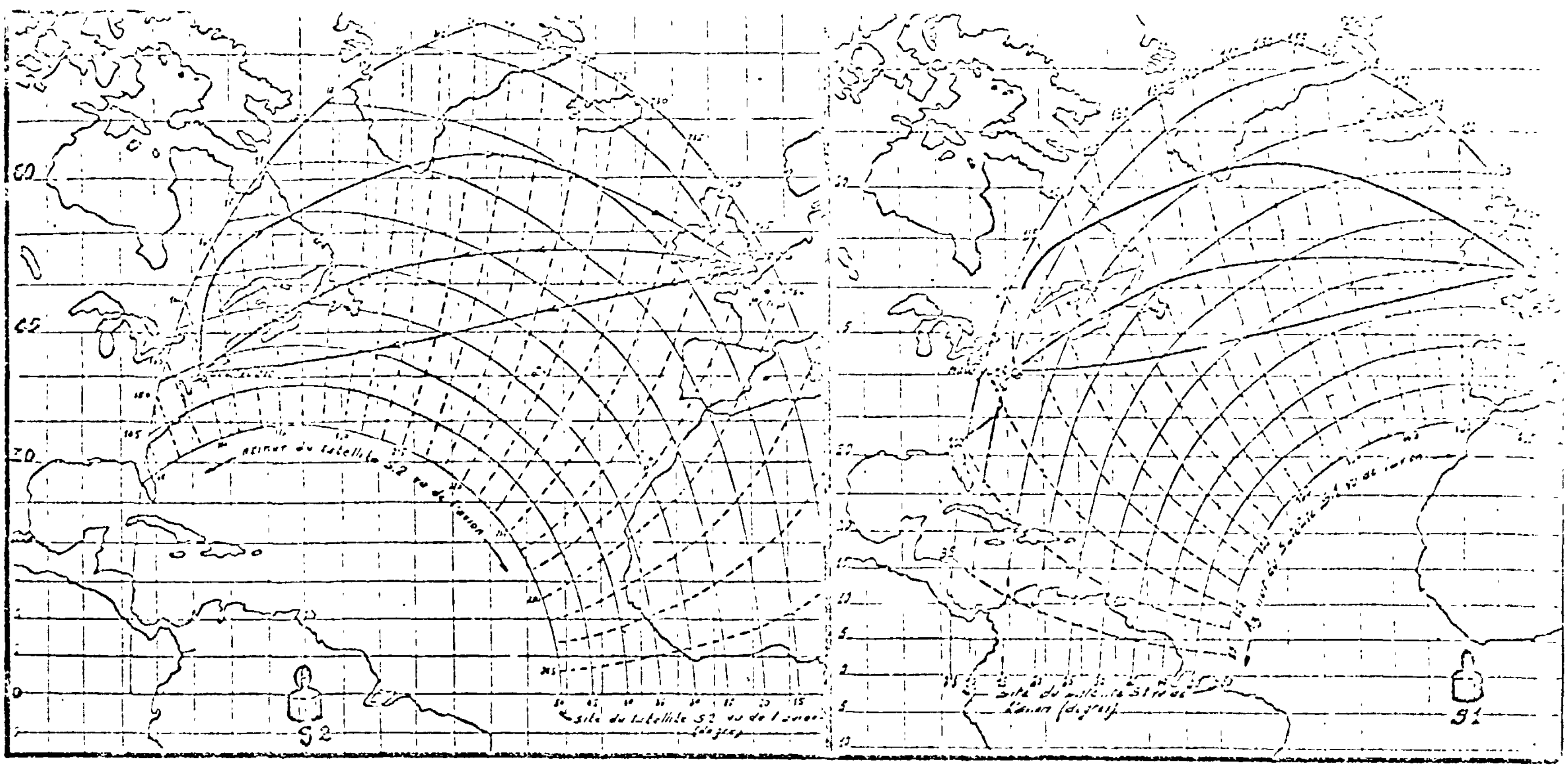

Figure 5. These diagrams show the asimuthside angles for airplanes seen from satellites S2 (left) and S1 (right).

"Ears" of Six Meters on the Ground

It has been shown that a single ground station can handle the position-plotting of all airplanes. However, in practice two such stations would exist, one on each side of the Atlantic; other control centers would also obtain information, and one can plan other telecommunication stations. The principal stations will alternate as "Master" in the position-finding. The other station would in the meanwhile receive information plotted by the Master station, but would be ready to relay it in case of a breakdown. By providing essential installations for each station, each could easily handle maintenance, without hindering the functioning of the system.

Each station will be provided with two antennas, 6 meters in diameter, with restricted orientability, the beams of which will have widths 0.7° between the 3 dB points. Each station will include a 10 W transmitter for telecommunications, and a 5 W transmitter for position-finding signals. The functioning of the link is satisfactory so that it would be sufficient to provide parametric amplifiers without cooling (sound temperature: 300° K) for reception.

The computer at each station, redundant to provide reliability, will carry out the following functions: position plotting of each aircraft, tracking each airplane; disclosing the ephemerides of satellites; evaluating collision risks; informing the controllers of the situation; preparing control messages.

In addition to the telemetric laser position-finding system of the satellites, an auto-calibrating installation will be used; the system involves the simulating of three airplanes on the ground at geodesically relayed points. After having estimated the cost of the installation, the specialists of the C.N.E.S. are at present studying the economic aspects of its operation. The first results are encouraging. We will discuss them later.

The mathematical definition of certain parameters, such as variations of L frequency band transmissions, is being studied at present from the viewpoint of classification. This is done at the request of international agencies which show more and more interest in the French project, as the research reports of our specialists are being received.

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